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Jet Shapes at HERA

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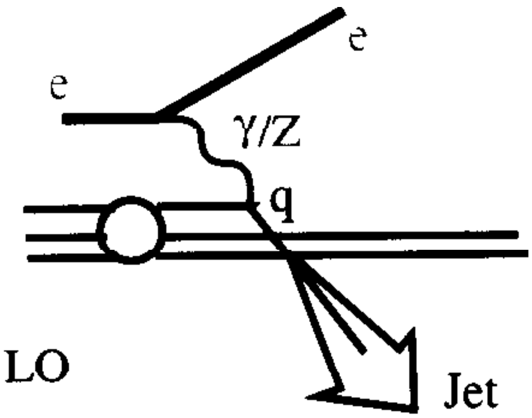
for

ZEUS Collaboration

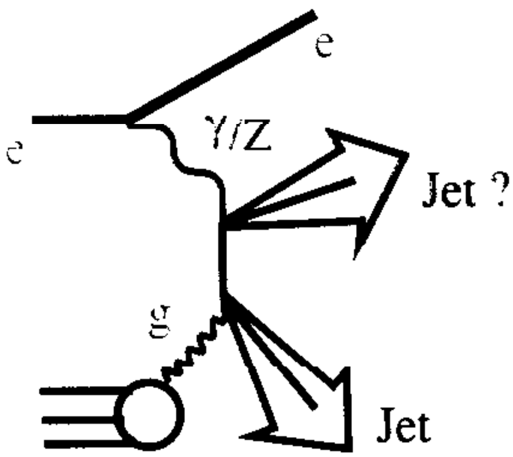
- Introduction.
- Jet Shape definition.
- Photoproduction Jet Shapes.
- Comparison with NLO calculations.
- DIS Neutral Current Jet Shapes.
- Comparison of γp and DIS NC.
- Comparison with e^+e^- and $p\bar{p}$.

INTRODUCTION

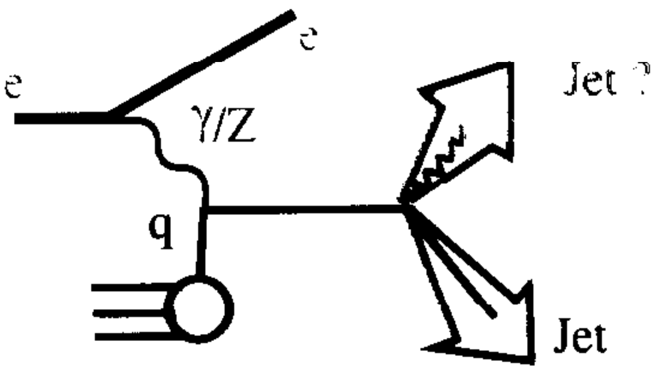
• Deep-Inelastic Scattering Processes.



LO



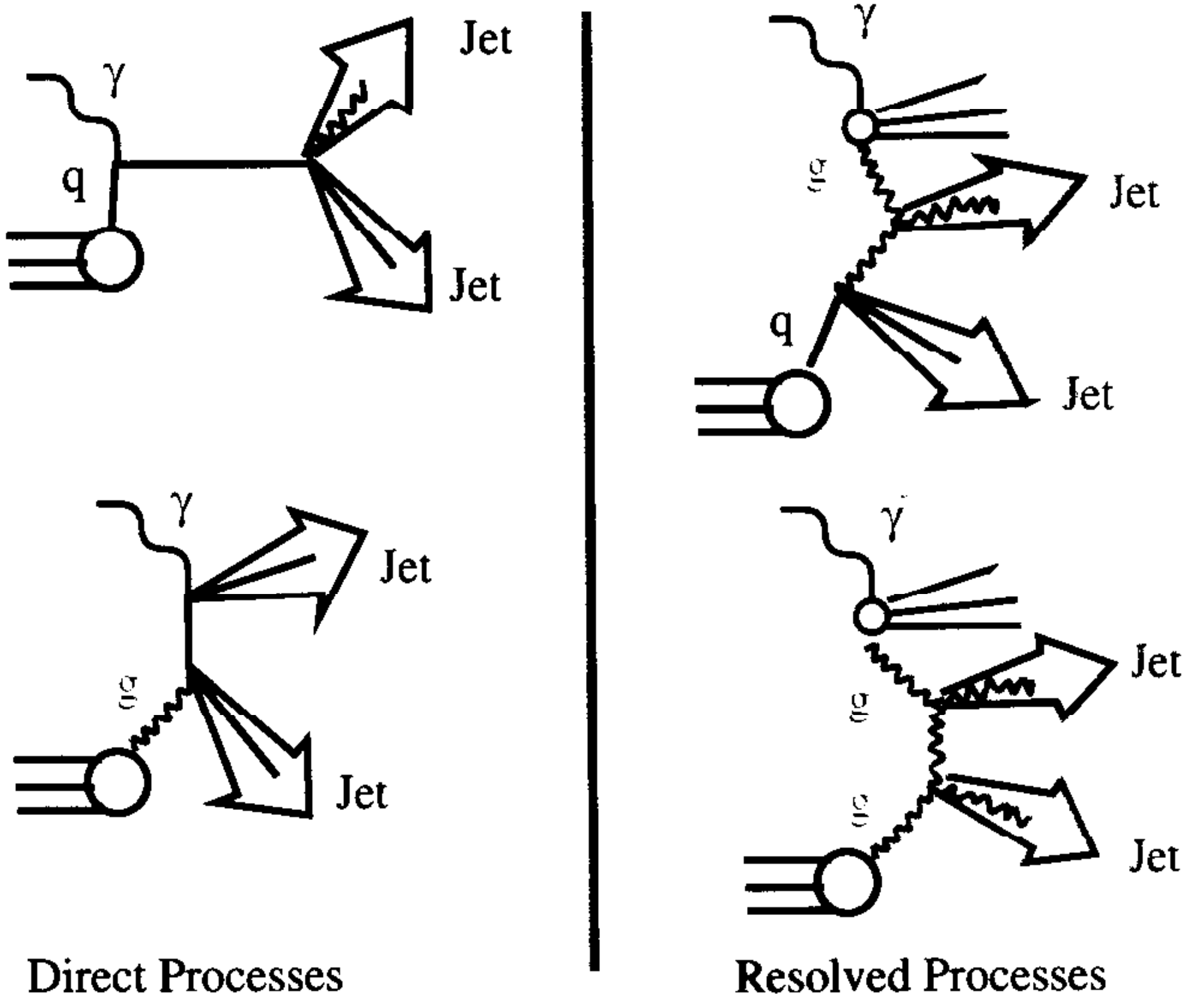
BGF



QCDC

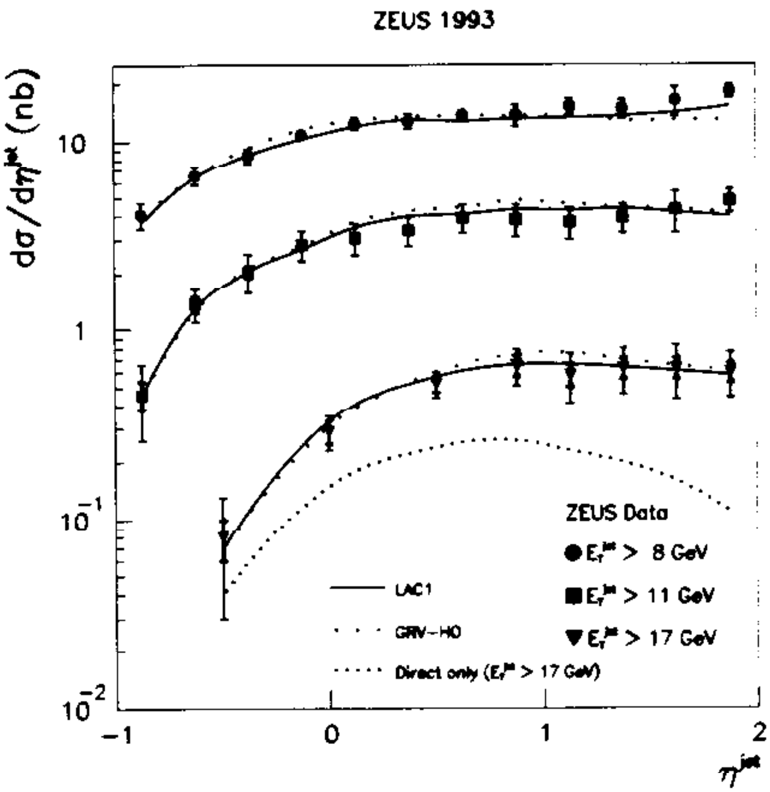
- $Q^2 > 100$ GeV^2.
- At least one jet with $E_T^{jet} > 14$ GeV and $-1 < \eta^{jet} < 2$.

• Hard Photoproduction Processes.

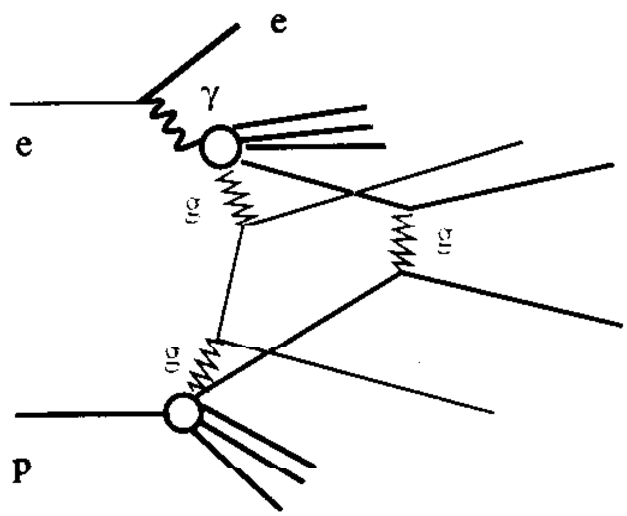


- $Q^2 < 4$ GeV^2.
- $0.2 < y < 0.85$
- At least one jet with $E_T^{jet} > 14$ GeV and $-1 < \eta^{jet} < 2$.

– The resolved processes dominate in the forward region.

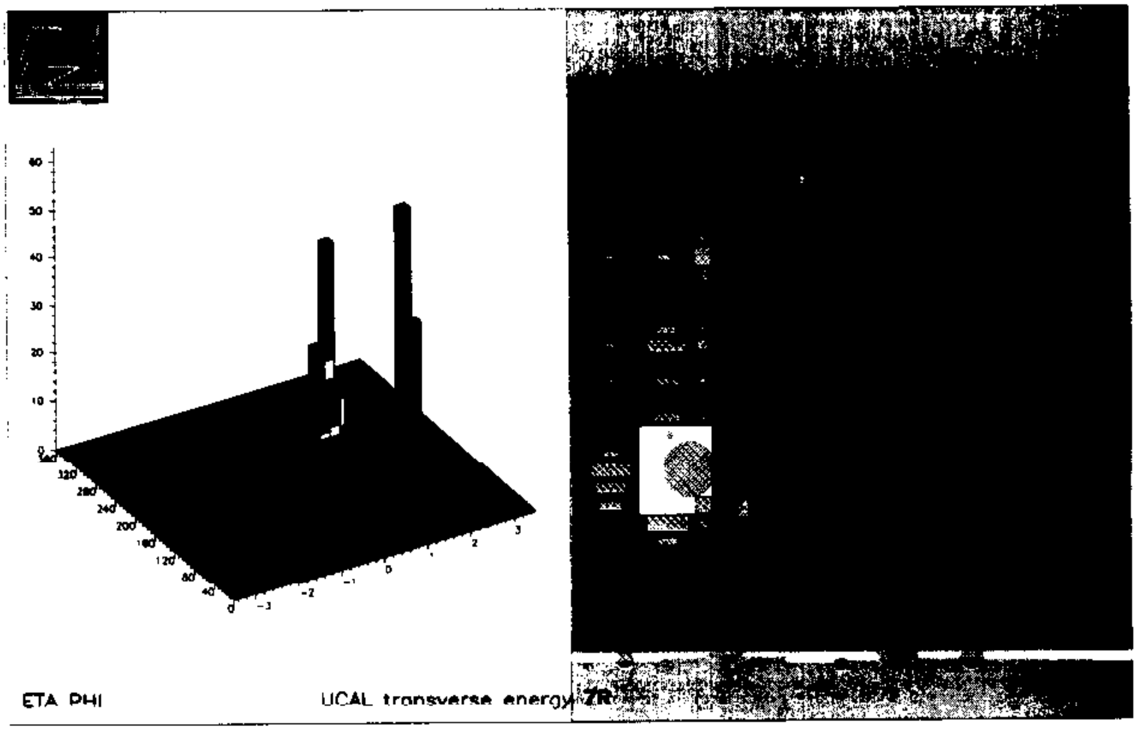


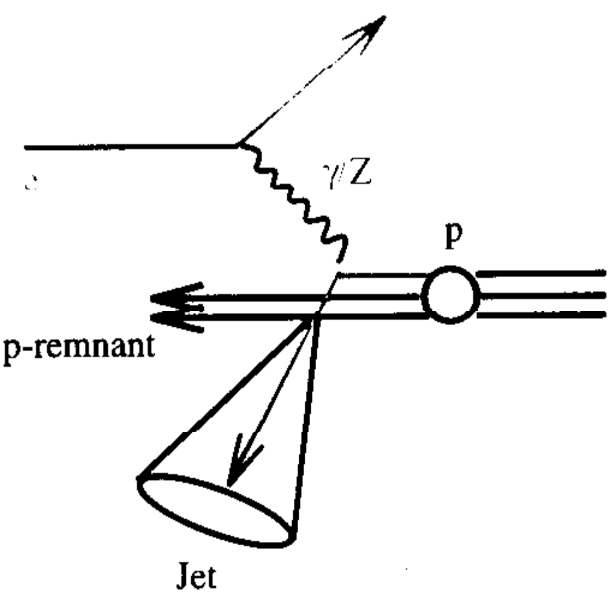
– Multiple Interaction (MI) model:



More than one interaction per event

Reconstruction of Jets

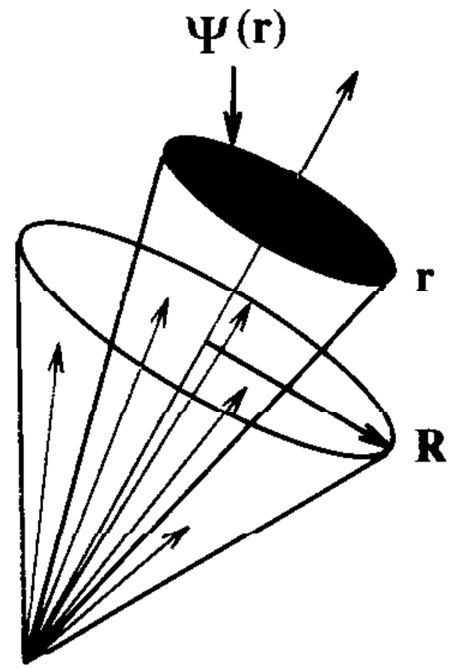




- A cone algorithm in $\eta - \phi$ space is used to reconstruct jets with a radius $R = 1$ unit.

JET SHAPE DEFINITION

The jet shape is defined as the average fraction of the transverse energy of the jet which lies inside an inner cone of radius r concentric to the jet cone.

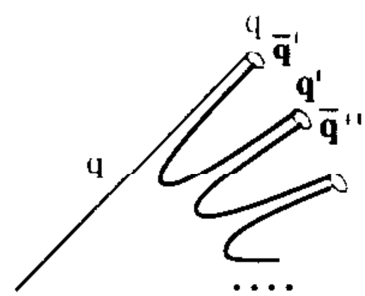


$$\Psi(r) = \frac{1}{N_{jets}} \sum_{jets} \frac{\Sigma_{k<r} E_T(k)}{\Sigma_{k<R} E_T(k)}, \qquad 0 < k < r$$

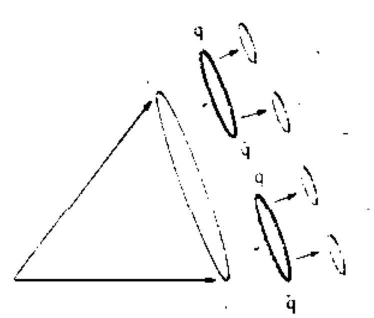
- The Jet Shapes are measured using the calorimeter.
- **The Jet Shapes are corrected back to the hadron level.**

Independent Fragmentation
(The Simplest Model)

- The outgoing partons are assumed to fragment indepently.
- For each primary parton — additional $q\bar{q}$ pairs are created and combined to form mesons.
- **The sharing of longitudinal momentum is given by the fragmentation function $f(z)$**
- **The relative transverse momentum follows a gaussian distribution with a width of** $\sim$ [illegible] MeV.

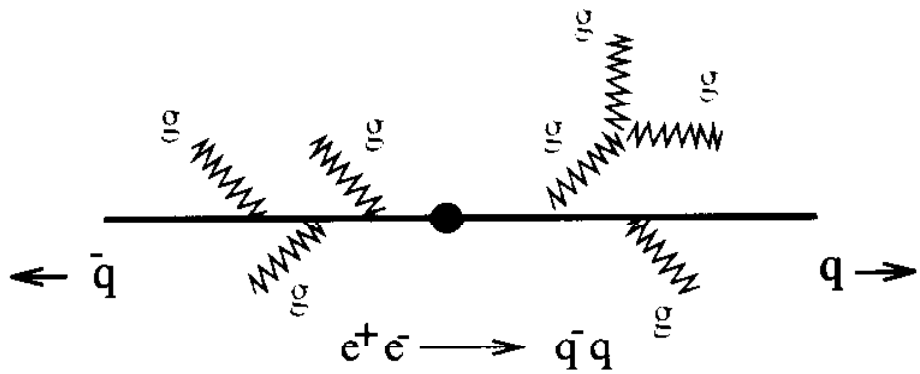


String Fragmentation
(An Improved Model)



QCD Parton Radiation

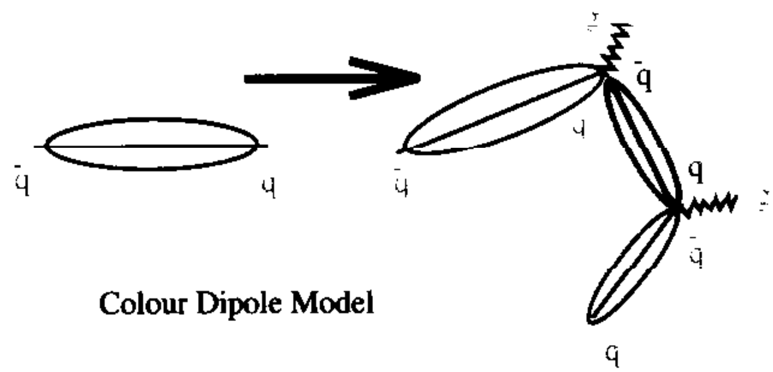
• Final Parton Shower



– Multiparton processes are produced using MC simulations based in the Leading Logarithm Aproximations.

As the shower evolves. the virtuality of the partons diminish (a cut-off Q^2 [illegible] is introduced in order to keep α_s small).

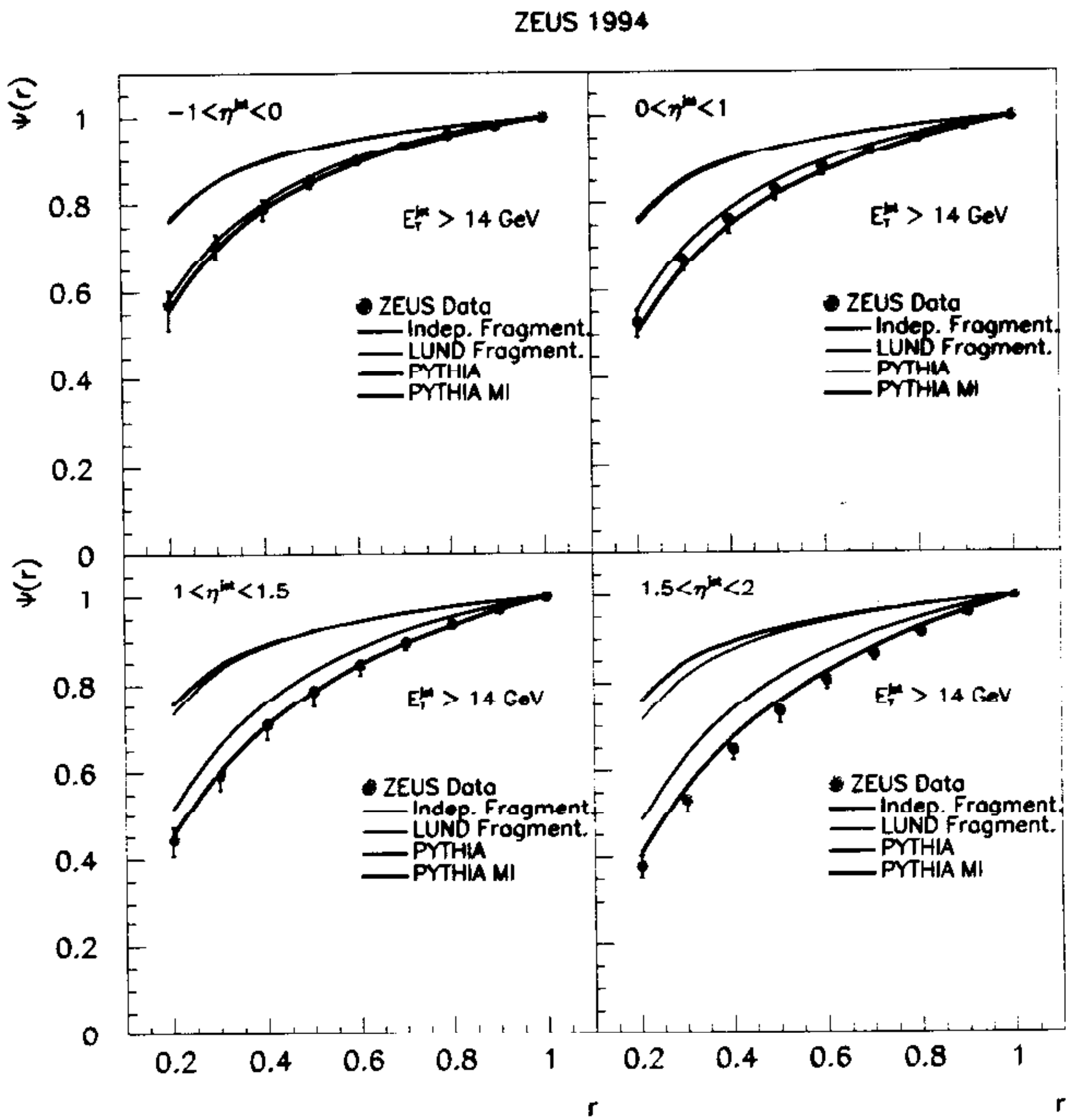
• Colour Dipole Model



Colour Dipole Model

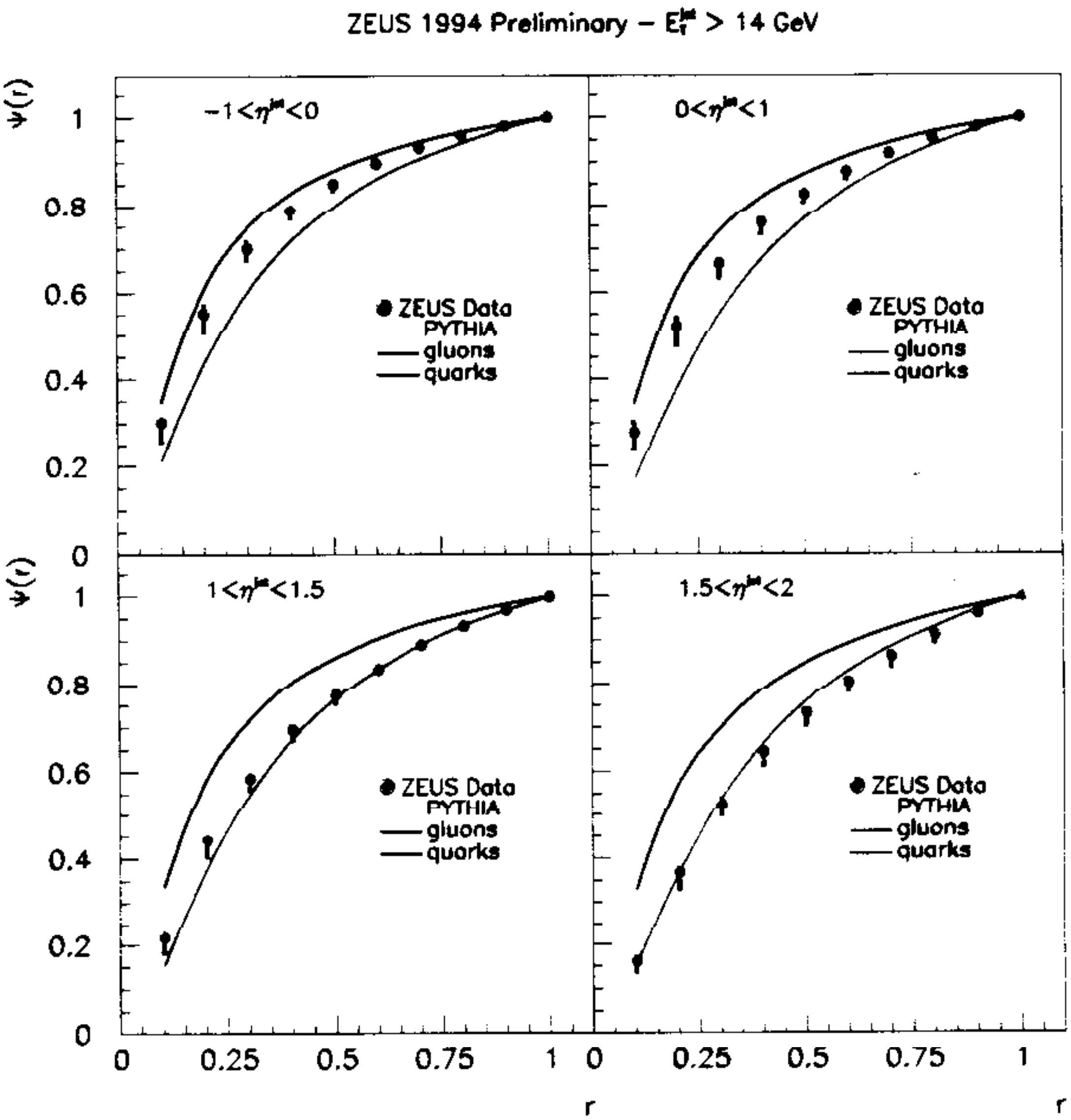
- The physical state can be described from the energy-momentum and polarization of all the dipoles.
- When one dipole radiates a gluon it is split into two dipoles.

Jet Shapes in Photoproduction



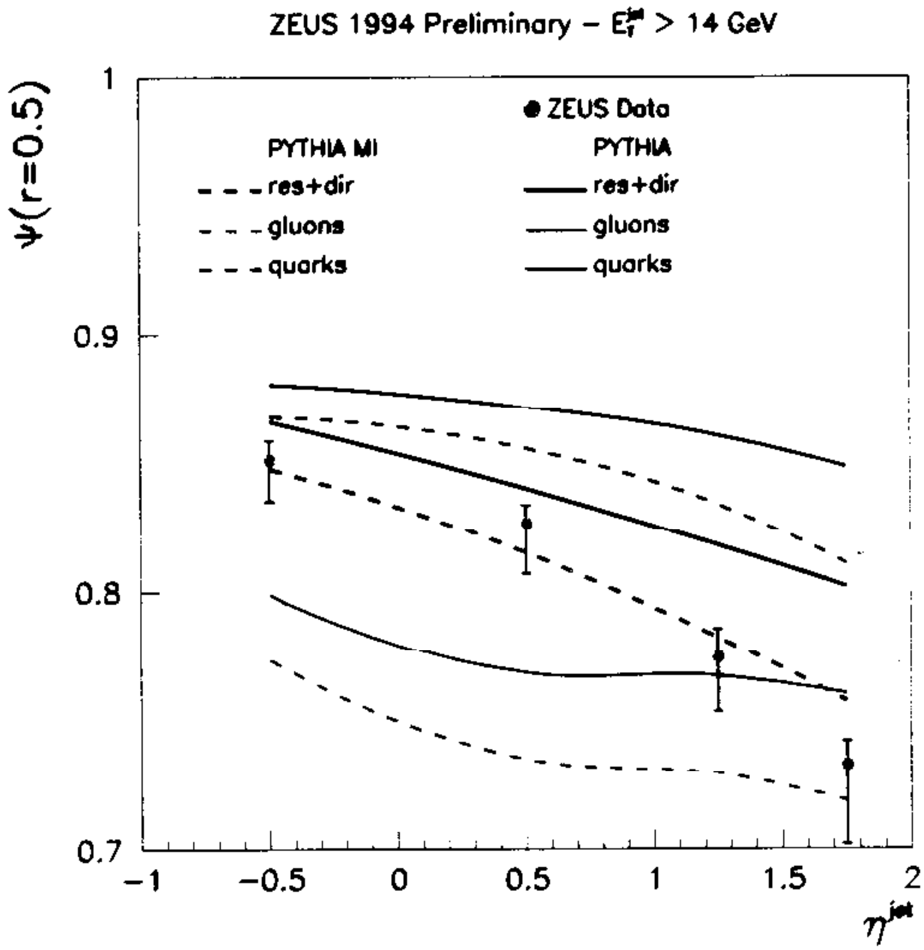
- The effects of the fragmentation on the jet shapes are small.
- The Jet Shape is dictated mainly by QCD radiation.

Jet Shapes in Photoproduction



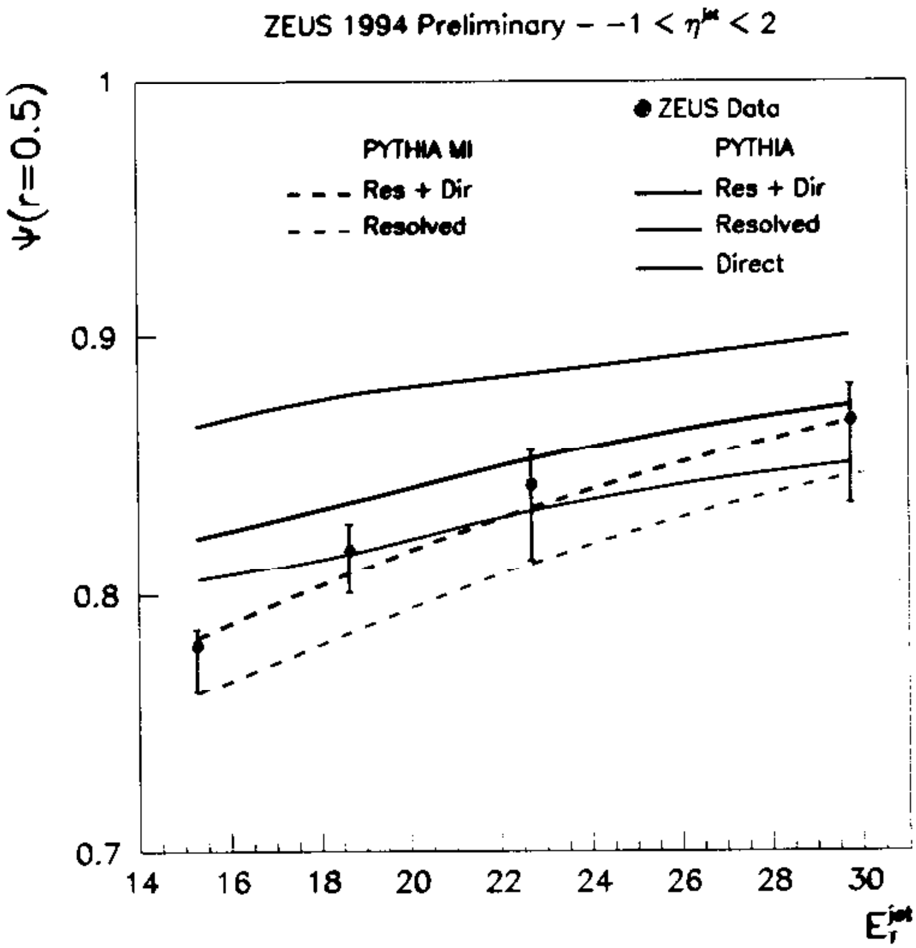
- The broadening of the jet shape as η^{jet} increases is consistent with an increasing fraction of gluon jets.

Jet Shapes in Photoproduction



- The broadening of the measured jet shape as η^{jet} increases is consistent with the increase of the fraction of the gluon jets predicted by PYTHIA once the uncertainty due to a possible underlying event is taken into account.

Jet Shapes in Photoproduction



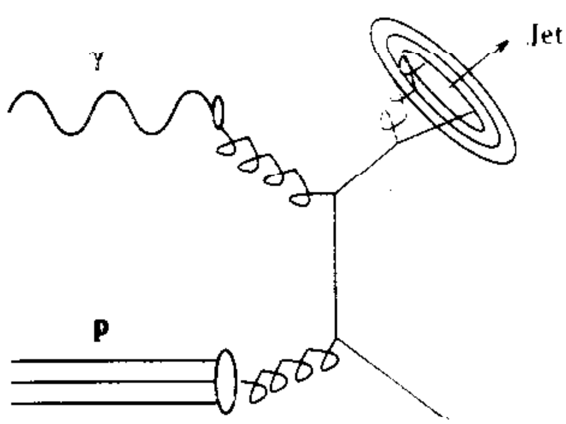
- The moderate E_T^{jet}-dependence of the measured jet shapes is not an artifact of a possible underlying event.
- The inclusion of the MI improves the description of the data in the lowest E_T^{jet} region.

NLO QCD Calculation in γp

- **Jets are reconstructed using a cone algorithm as in the data.**
- Up to three partons in the final state — no more than two partons within a jet.
- In NLO, $(1-\Psi(r))$ is computed in order to avoid collinear singularities.

$$1-\Psi(r) = \frac{\int_r^R dE_T E_T [d\sigma(\gamma p \to 3\mathrm{partons} + X)/dE_T]}{(E_T^{jet}\sigma(E_T^{jet}))_{LO}}$$

- $1-\Psi(r)$ is $O(\alpha_s)$ → **The jet shape is calculated only to lowest nontrivial order.**



NLO QCD Calculation in γp

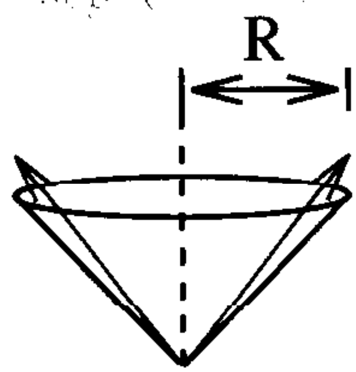
G. Kramer and S. Salesch (Phys. Lett B 317 (1993) 218)

M. Klasen and G. Kramer (DESY-Preprint 97-002)

- **Renormalization scale :** $\mu = E_T^{jet}$
- **1-loop** α_s
- Resolved and Direct processes
- Weizsäcker-Williams approximation

- **Parton distributions:**
  Proton (CTEQ4) Photon (GRV-HO)

- Merging: R_{sep} (Ellis,Kunszt,Soper)

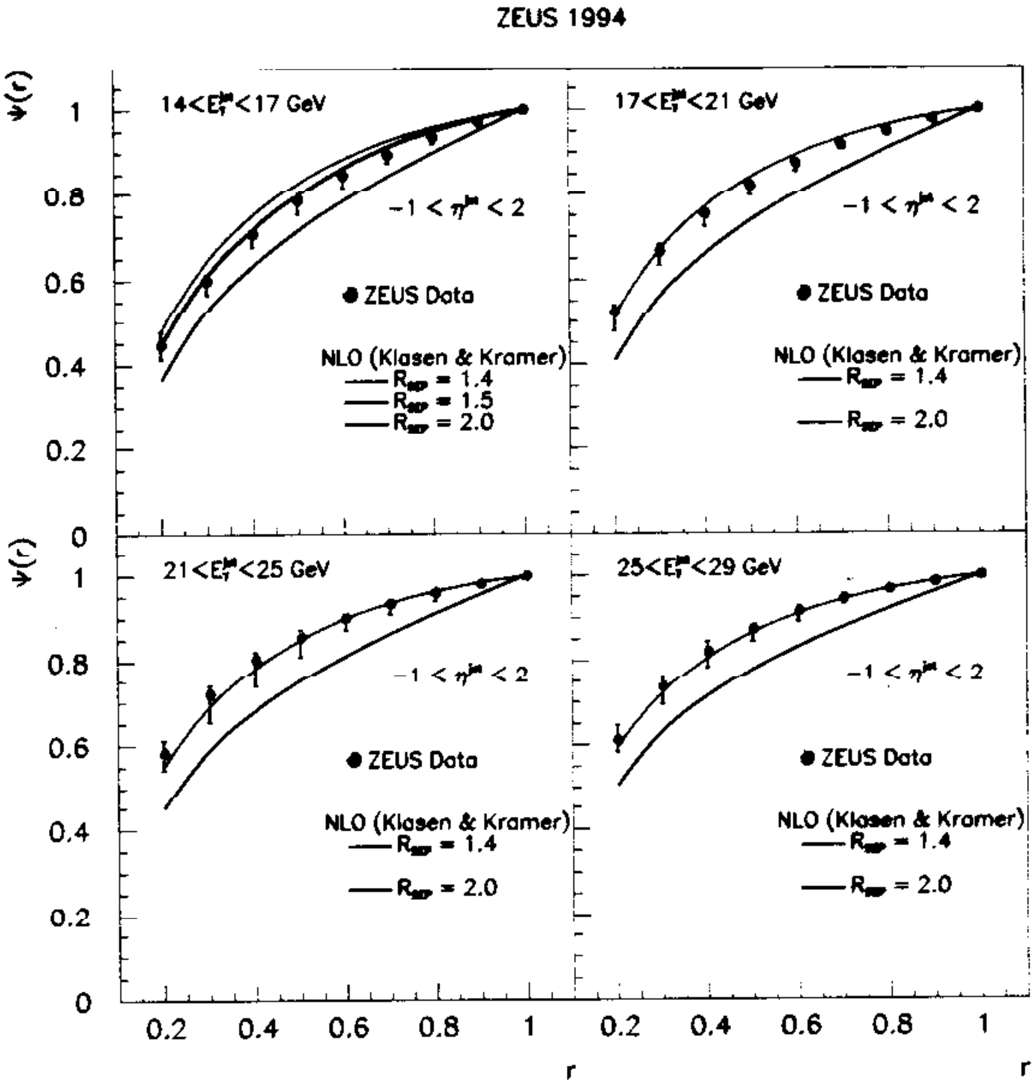


two partons are combined if

$$\Delta = \sqrt{\Delta\eta_{12}^2 + \Delta\phi_{12}^2} < \min\left(\frac{E_T^{jet\,1} + E_T^{jet\,2}}{\max(E_T^{jet\,1}, E_T^{jet\,2})} R,\ R_{sep}\right)$$

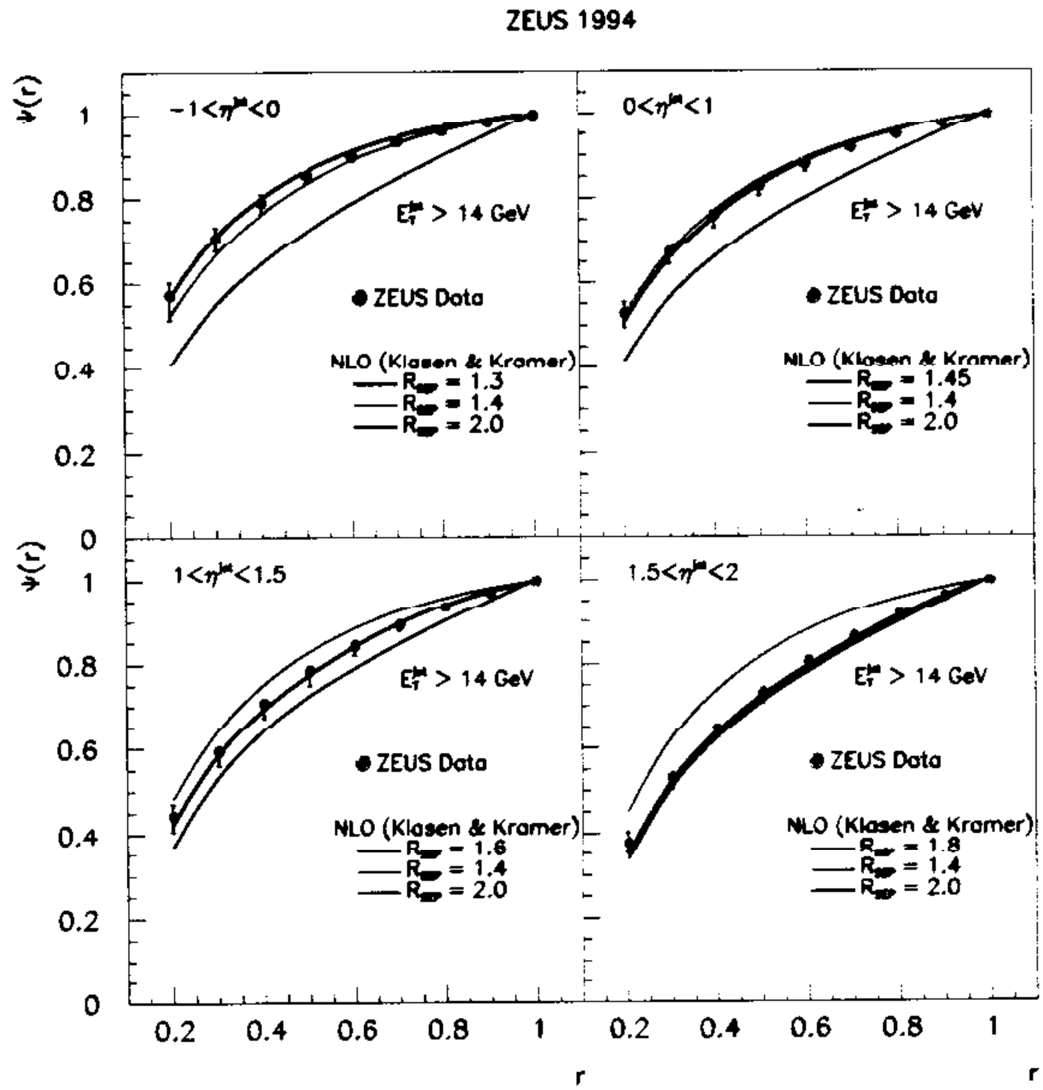
There is a strong dependence on μ **and** R_{sep}

NLO QCD Calculation in γp



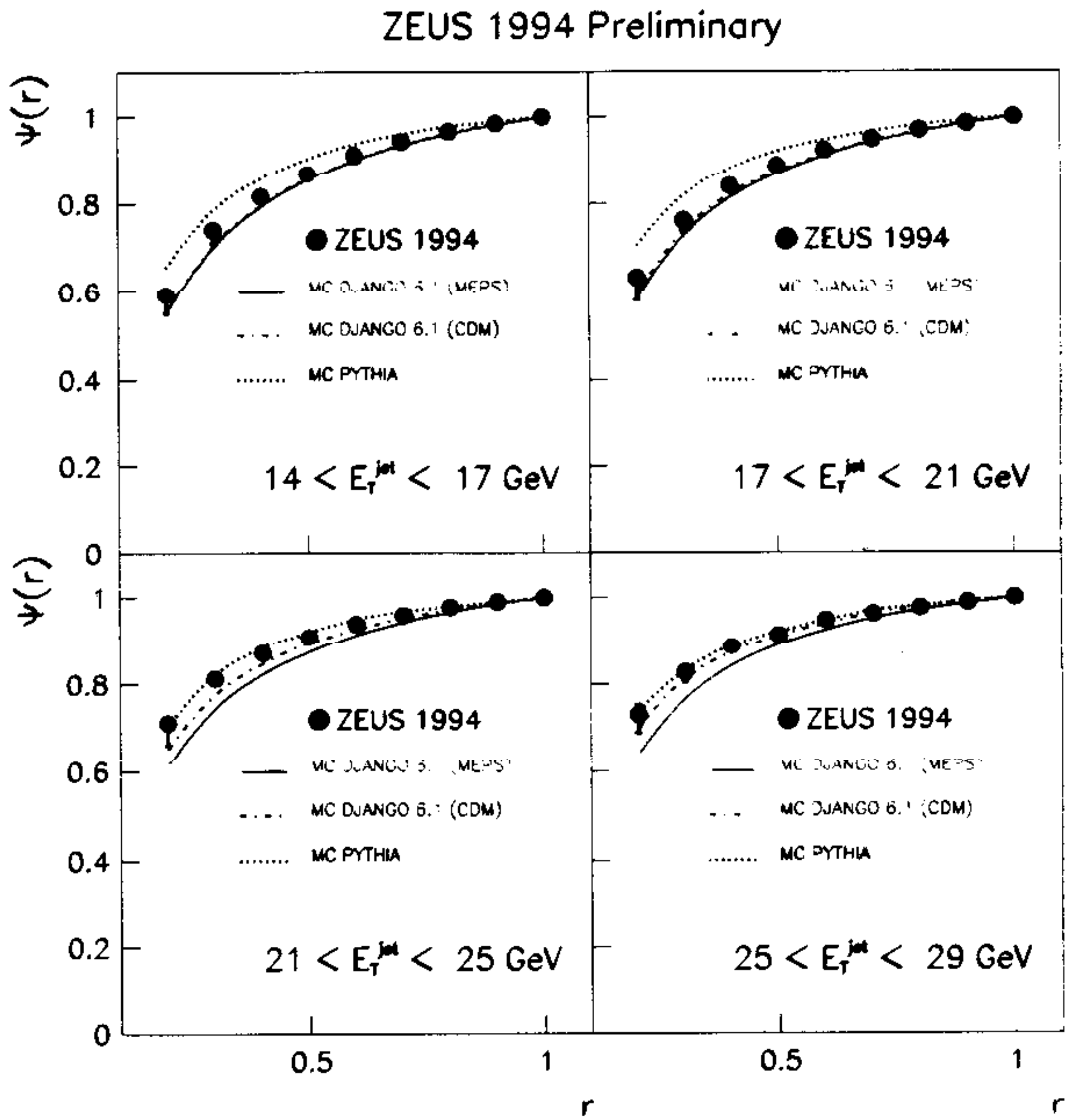
- NLO QCD calculations at the parton level are able to describe the measured jet shapes.
- For the E_T^{jet} dependence with $R_{sep} = 1.4$, except for the lowest E_T^{jet} region.

NLO QCD Calculation in γp



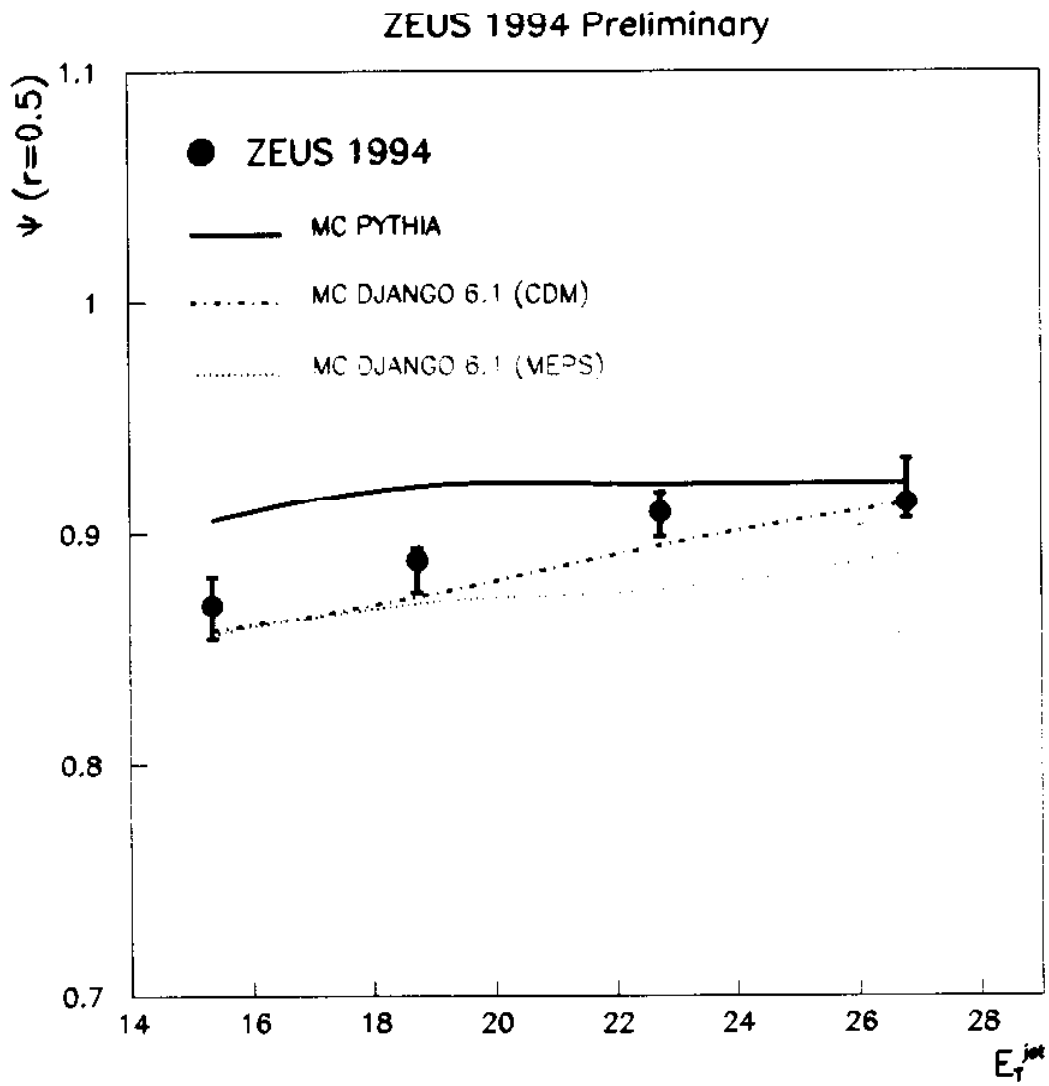
- For the η^{jet} dependence the NLO calculations describe the data after choosing appropriately the value of R_{sep} in each η^{jet} region.

Jet Shapes in Neutral Current DIS



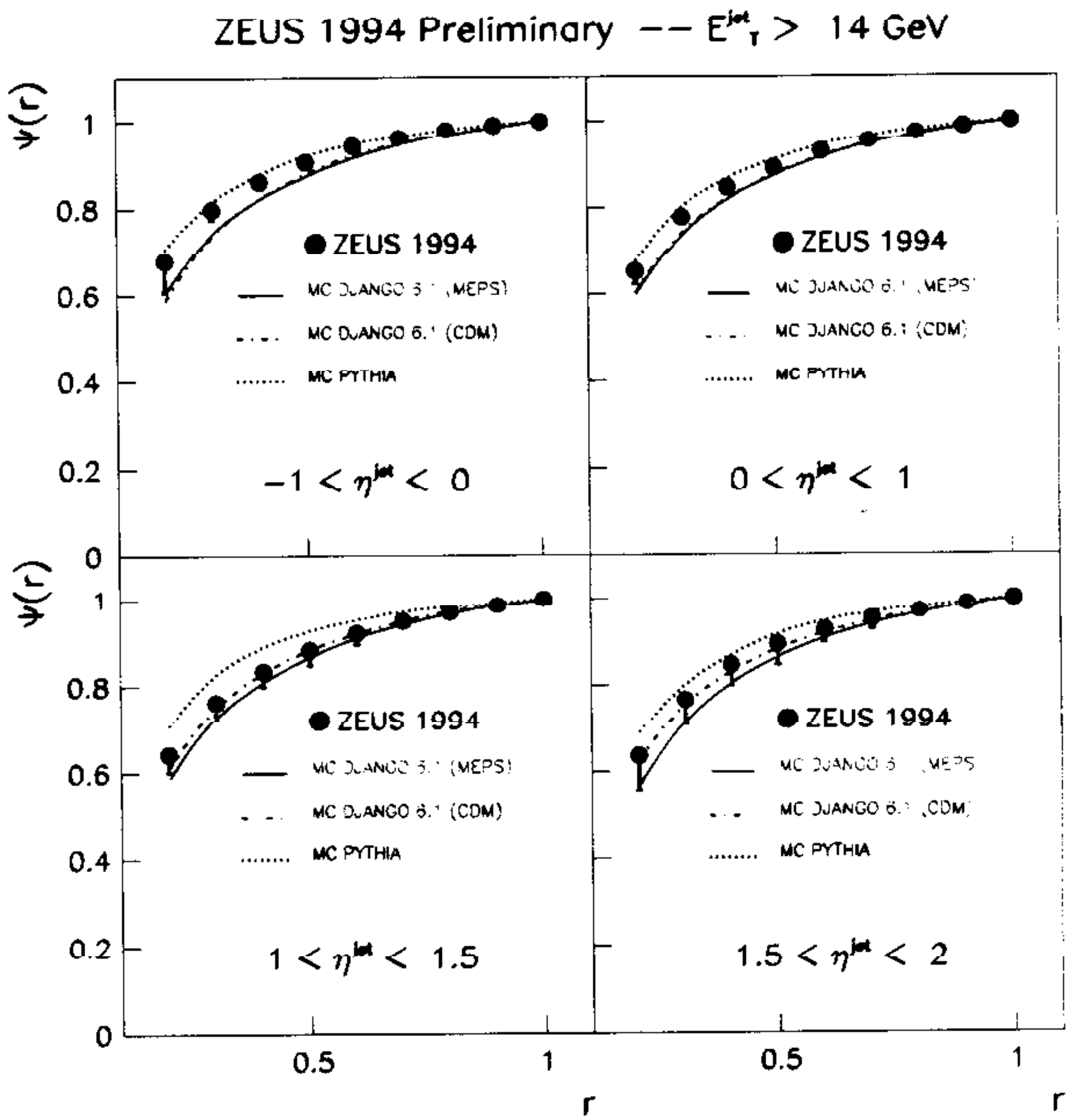
- LO + PS (PYTHIA) describes the high E_T^{JET} region very well.
- LO + QCDC + BGF + PS (DJANGO MEPS) produces jets slightly broader than the measured jets.
- LO + CDM + BGF (DJANGO CDM) is better in the high E_T^{jet} region than PS.

Jet Shapes in Neutral Current DIS



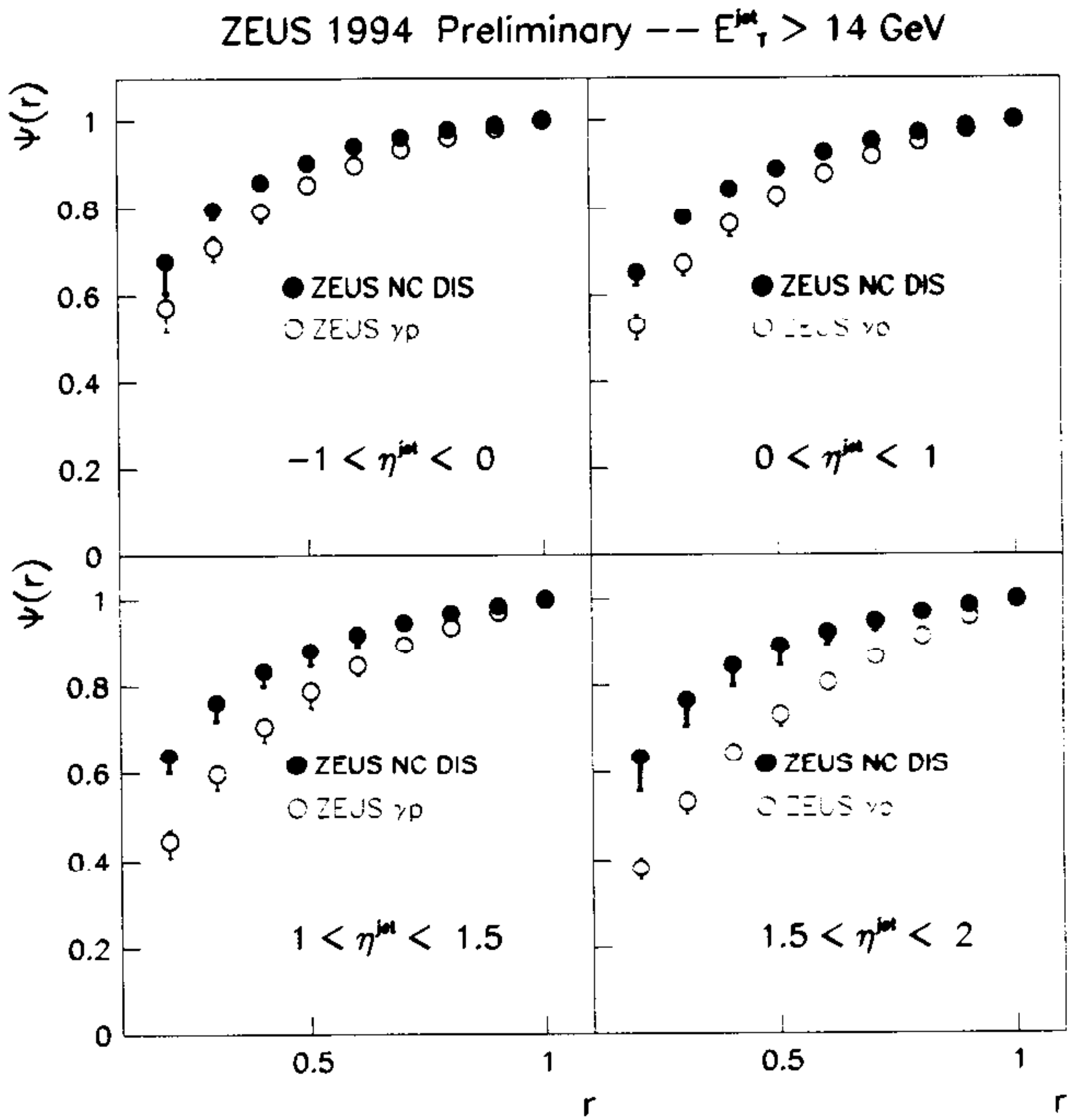
- A moderate E_T^{jet}-dependence of the measured jet shapes is observed: the jet shape narrows as E_T^{jet} increases.

Jet Shapes in Neutral Current DIS



- No significant dependence on η^{jet} is observed in the data.
- CDM Model seems to be better than the Parton Shower Model in the forward region.

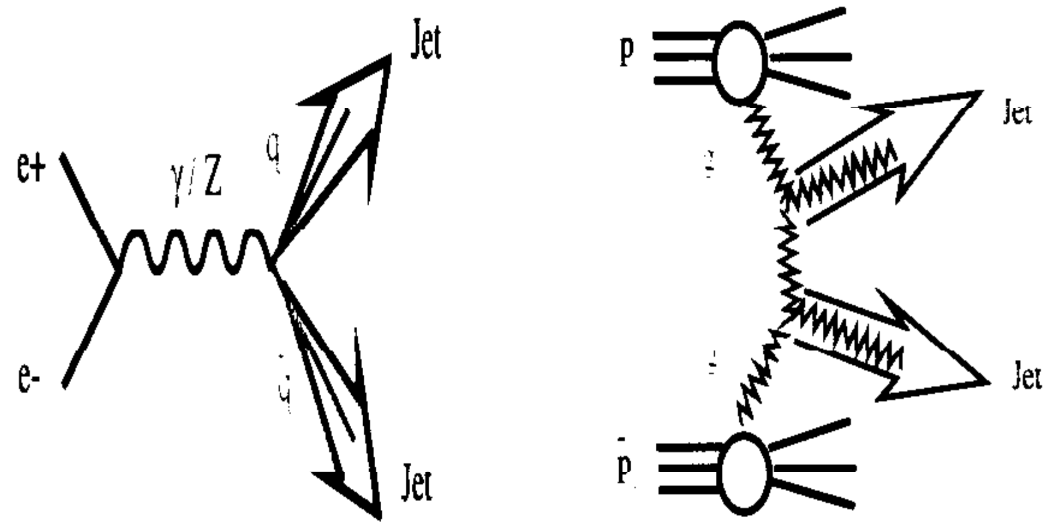
NC DIS and γp Jet Shapes



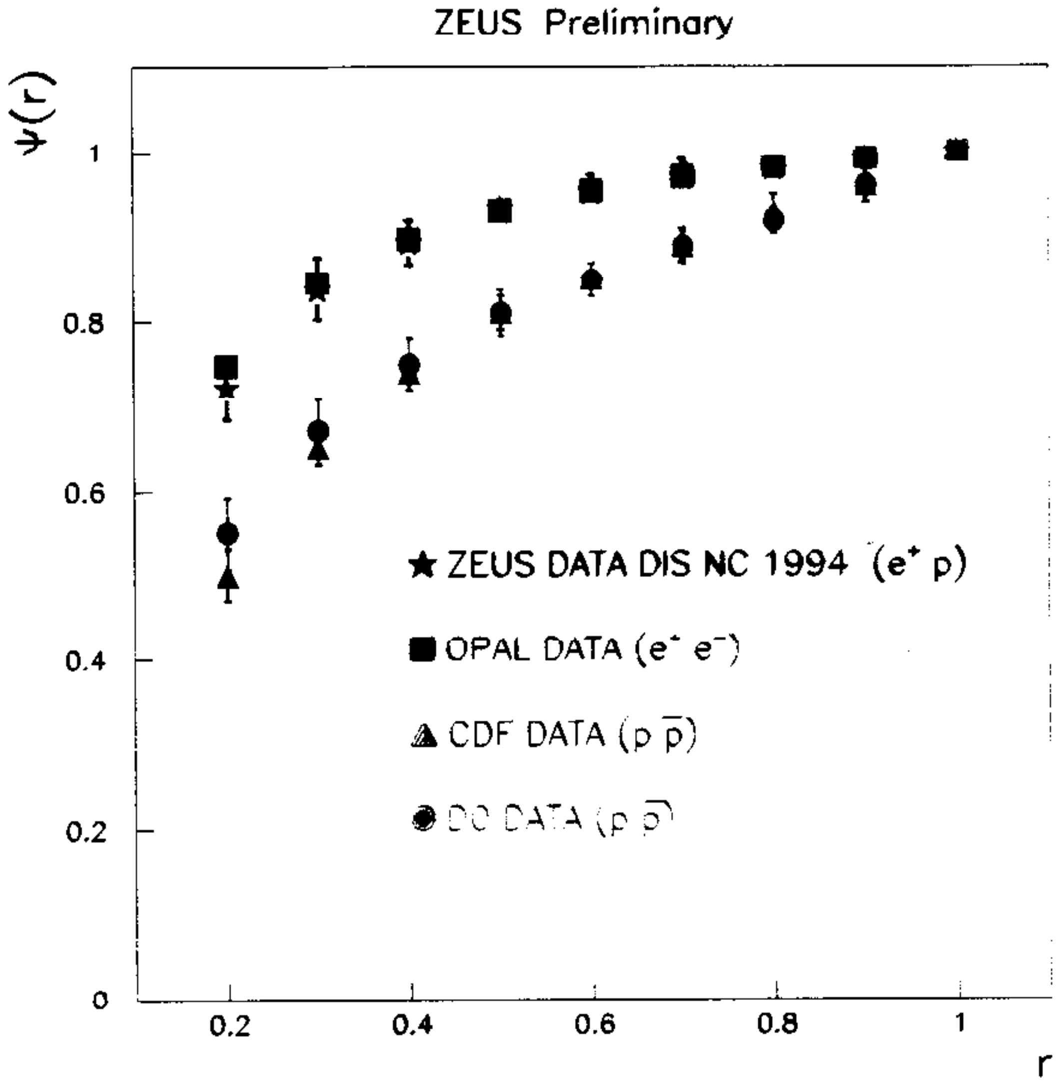
- The observed differences increase as η^{jet} increases $\rightarrow$ the resolved γp processes dominate in the forward region.

Comparison to e^+e^- and $p\overline{p}$

- **ZEUS (NC DIS):**
  Jets with $37 < E_T^{jet} < 45$ GeV
- **OPAL :**
  Jets with $E^{jet} > 35$ GeV
- **CDF :**
  Jets with $40 < E_T^{jet} < 60$ GeV
- D0 :
  Jets with $45 < E_T^{jet} < 70$ GeV



Comparison to e^+e^- and $p\bar{p}$



- ZEUS and OPAL → High E_T^{jet} jets predominantly coming from quarks. The results from ZEUS and OPAL are very similar.

- CDF and DO → contributions from high E_T^{jet} jets predominantly coming from gluons.

Summary and Conclusions

- The Jet Shapes in Photoproduction and DIS NC events have been measured for jets with $E_T^{jet} > 14$ GeV.

- **Jet Shapes in γp**

  - **The effects of the fragmentation on the jet shapes are small. The shape of the jet is dictated mainly by the QCD radiation.**

    The broadening of the jet shape as increases is consistent with the increase of the fraction of gluon jets.

  - **The jet shape narrows as E_T^{jet} increases**

  - **The inclusion of the MI (underlying event) improves the description of the lowest E_T^{jet} and highest η^{jet} regions.**

  - **The lowest order QCD non-trivial contribution to the jet shape is able to describe the γp jet shapes (the parameter R_{sep} must be included).**

- **Jet Shapes in NC DIS**

  - **No significant dependence of the shape of the jet as η^{jet} increases is observed.**

    The jet shape narrows as E_T^{jet} increases.

  - **Leading Logarithm parton shower Monte Carlo calculations** without $O(\alpha_s)$ hard subprocesses **produce jets slighly narrower compared to the data at low E_T^{jet}.**

- The inclusion of the next QCD order subprocesses (CDM or MEPS) improves the description of the data.
- The Colour Dipole Model for the QCD cascade seems to follow the data better that a Parton Shower Model in the highest E_T^{jet} and η^{jet} regions.

- **Comparison γp and NC DIS Jet Shapes.**
  - The photoproducted jets are broader than the jets in NC DIS: the differences increase as η^{jet} increases and decrease as E_T^{jet} increases (due to the dominance of resolved processes, which produce final state gluon jets, at large η^{jet} and low E_T^{jet}).

- **Comparison to e^+e^- and $p\bar{p}$.**

  The jet shapes measured in NC DIS [illegible] GeV^2 by ZEUS are very similar to the measured in e^+e^- by OPAL, and narrower than those in $p\bar{p}$ by CDF and D0 (for similar ranges in E[illegible]).